Effects of food intake, rumen development and live weight of calves of replacing barley with sugar beet-citrus pulp in a starter diet

Journal Item

Anim. Prod. 1987, **44**: 65-73
0003-3561/87/69290065$02·00

EFFECTS ON FOOD INTAKE, RUMEN DEVELOPMENT AND LIVE WEIGHT OF CALVES OF REPLACING BARLEY WITH SUGAR BEET-CITRUS PULP IN A STARTER DIET

P. E. V. Williams, R. J. Fallon, G. M. Innes and P. Garthwaite
Rowett Research Institute, Greenburn Road, Bucksburn, Aberdeen AB2 9SB

ABSTRACT

In three experiments the effects of replacing barley with citrus or unmolassed beet pulp in starter diets for calves was examined. In experiment 1, 40 Friesian bull calves were offered to appetite from 14 to 91 days of age one of four complete pelleted diets, each of which contained 200 g ground straw per kg and in which the ratio of barley to pulp (citrus and beet pulp in the ratio 1:1) was 100:0 (A); 67:33 (B); 33:67 (C) and 0:100 (D). All diets contained 12·1 MJ metabolizable energy and 187 g crude protein per kg dry matter (DM). Milk replacer containing 200 g fat per kg was offered once daily (0·44 kg/day) until day 49 when the calves were abruptly weaned. Up to weaning (days 14 to 49) and after weaning (days 50 to 91) intake of DM was significantly increased by replacing barley with pulp ($P < 0·05$). Intakes (kg DM per day) of diets A, B, C and D were 0·31, 0·44, 0·51 and 0·50 before weaning and 2·07, 2·08, 2·23 and 2·38 after weaning. Weight gains (kg/day) of calves given pulp tended to be higher before weaning (0·44 *v.* 0·58 for A *v.* mean of B, C and D) but lower after weaning (0·73 *v.* 0·68) than of calves given the cereal-based diet. In experiment 2, 65 calves were given diets similar to A and C except that the pulp was supplied totally by unmolassed beet pulp, they were given only 0·35 kg milk replacer per day and weaned on day 35. The results were similar to those obtained in experiment 1; between days 14 to 84 intake was higher ($P < 0·05$) and there was a tendency for weight gain to be higher in calves given the diet containing pulp. The DM digestibility of the diets decreased significantly with inclusion of pulp ($P < 0·05$); digestibility of nitrogen was severely depressed but there was an increase in digestibility of acid-detergent fibre. Growth rate was possibly restricted by the availability of nitrogen in diets containing pulp.

INTRODUCTION

Traditionally calf starter rations have been formulated containing cereals as the major source of energy. In experiments which have demonstrated a beneficial effect on intake from the inclusion of roughage in all-pelleted diets based on cereals, the appetite of the calf may have been constrained by low fibre digestion (Thomas and Hinks, 1983; Williams, Innes, Brewer and Magadi, 1985b). Furthermore, although it is uncertain whether addition of sodium bicarbonate to the diet increases food intake of young calves by raising rumen pH, of those factors related to the rumen environment, pH was the factor most closely correlated with variation in intake (Williams *et al.*, 1985b) and in calves given roughage raising rumen pH might increase cellulose digestion (Mould, Ørskov and Mann, 1983/84). A. Silva (personal communication) showed that unmolassed sugar-beet pulp can be used to supplement straw without causing the same depression in cellulolysis as an equivalent amount of energy supplied by cereal grain, since the fermented material was cell-wall polysaccharides rather than starch. The experiments described here were designed to examine the effect of replacing cereals with citrus and sugar-beet pulp in calf starter diets which contained straw and to measure appetite and the digestibility of the components of the diets.

MATERIAL AND METHODS

Experiment 1

Animals. Forty autumn-born Friesian bull calves were purchased locally when they were 4 days of age (day 4) and allocated to experimental treatment on arrival. They were given their first feed of milk replacer the following morning and were bedded with sawdust in individual cubicles in a calf house with controlled ventilation. Each calf received 0·10 kg milk replacer dissolved in 1 l of warm water (39°C) twice daily and drinking water was constantly available. The allowance of milk replacer was gradually increased until on day 14 each calf was offered 0·44 kg milk replacer (dry matter (DM) of milk replacer = 0·948, 0·928 and 0·943 g/kg in experiments 1, 2 and 3 respectively), in 3 l warm water once daily. This level of feeding continued until they were weaned on day 49. A pelleted dry food was given to appetite from day 14 onwards. Fresh food was supplied dail and refusals were recorded. All calves were weighed at 7-day intervals until the experiment terminated when the calves were 91 days of age.

TABLE 1

Composition and chemical analysis of diets containing different proportions of barley and citrus/beet pulp offered to the calves

	Diet			
	A	B	C	D
Ratio of barley to pulp	100:0	67:33	33:67	0:100
Composition (g/kg DM)				
Ground barley straw	200	200	200	200
Rolled barley	533	355	177	0
Pulp (citrus + beet)	0	174	349	523
Soya	100	104	107	110
Megalac†	50	50	50	50
Fish meal	100	100	100	100
Minerals and vitamins	12	12	12	12
Urea	5	5	5	5
Estimated metabolizable energy‡ (MJ/kg DM)	12·07	12·07	12·06	12·06
Estimated crude protein‡ (g/kg DM)	188	188	187	187
Chemical analysis (g/kg DM)				
Experiment 1	A	B	C	D
Dry matter	840	834	828	822
Nitrogen	34	33	33	32
Lipid	70	65	62	66
Ash	77	90	98	109
Acid-detergent fibre	145	182	212	247
Experiment 2	A1		C1	
Dry matter	861		856	
Nitrogen	32		31	
Lipid	50		49	
Ash	88		108	
Acid-detergent fibre	176		241	

† (Megalac, Volac Ltd) — calcium palmitate with lipid and calcium concentrations (g/kg) of 850 and 90 respectively.

‡ Based on values given in MAFF (1975).

Diets. The milk replacer offered to the calves was a commercial formulation based on skim milk powder (600 g/kg) with a declared analysis of fat (200 g/kg) and protein (250 g/kg). Four different dry diets were prepared containing rolled barley and a mixture of sugar-beet and citrus pulp in the ratio 100:0, 67:33, 33:67 or 0:100 together with 200 g ground straw per kg (diets A, B, C and D respectively). The ingredients and chemical composition of the four diets are shown in Table 1. The pulp in the diet was supplied by a mixture of unmolassed sugar-beet pulp and citrus pulp in equal proportions and the diets were pelleted through a 4·8-mm die.

Experiment 2

Experiment 2 was conducted with 65 Friesian bull calves purchased at 4 days of age. The experimental protocol was the same as in experiment 1 except that the allowance of milk replacer was restricted to a maximum of 0·35 kg/day. The calves were weaned abruptly on day 35 and diets similar to diets A and C (A1 and C1 respectively; Table 1) were formulated but the pulp was totally supplied from unmolassed sugar beet. To minimize effects of different diets on gut fill, at the end of the experiment all calves were given diet A for 7 days and over the last 4 days they were restricted to an allowance of 2·5 kg food per day and live weights were recorded on the last 2 days.

Experiment 3

The digestibility of diets and nitrogen balance of calves in experiments 1 and 2 were measured using two extra groups of animals. Twelve additional Friesian bull calves were given the diets used in experiment 1 and a further 12 calves were given the diets used in experiment 2. The feeding protocol was the same as that employed in each growth trial and all dry diets were given to appetite. Total collections of urine and faeces were made over 10-day periods when the calves were restrained in metabolism cages. For the calves given diets A, B, C and D, collections started on day 38 (before weaning) and again on day 70 (31 days after weaning). For calves given diets A1 and C1 collections started on day 45 and again on day 78 (both periods after weaning). Digestibility and balance determinations were also made over a 7-day period starting on day 38, with four calves offered only 0·44 kg milk replacer in 3 l water once daily.

Statistical analyses

Daily live-weight gains and food intakes of calves in experiments 1 and 2 were first adjusted by covariance for differences in live weight at 14 days of age. Data relating to incremental inclusion of pulp was analysed by dividing the variation into its linear and quadratic components and testing for significant linear or quadratic contrasts by analysis of variance. The quadratic components of the contrasts were not significant and in Table 2 estimates of *b*, essentially the regression coefficient, were obtained from the linear contrasts, together with the s.e. of *b*, plus the level of significance. The estimated difference between diets containing only pulp or only barley is obtained by multiplying *b* by 100, and between any two adjacent diets by multiplying *b* by 25. Digestibility data were first tested for the effect of period and then for dietary effects. Since there were no period × diet interactions dietary effects were tested on data pooled for the two periods. Comparisons between the effects of diets A1 and C1 were made by Student's *t* test after adjustment by covariance for differences in initial live weight.

Chemical analysis

The DM concentration of diets and faeces was determined by oven drying for 48 h at

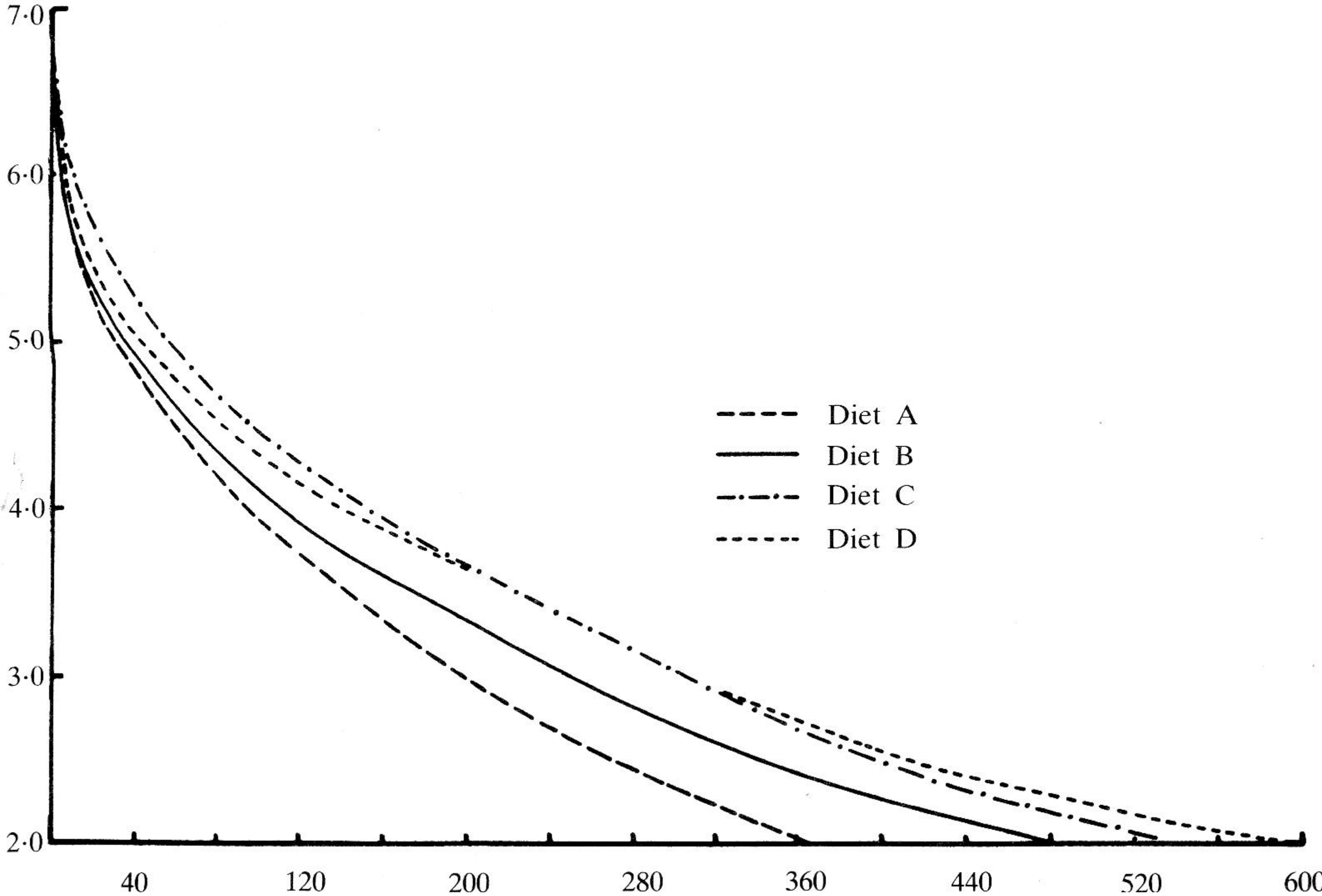
TABLE 2

Intake of dry matter (DM) and daily live-weight gains (kg/day) of calves, adjusted by covariance for differences in live weight at 14 days of age, offered diets containing different proportions of barley and citrus-beet pulp in experiment 1

	Diet						
	A	B	C	D	b	s.e. of *b*	Significance of dietary effect
No. of calves per treatment	10	10	10	10			
Intake (kg DM/day)							
Milk replacer							
days 14 to 49	0·42	0·42	0·42	0·42			
Pelleted diet							
days 14 to 49	0·31	0·44	0·51	0·50	−0·002	0·0009	*
days 50 to 91	2·07	2·08	2·23	2·38	−0·003	0·0015	*
days 14 to 91	1·27	1·33	1·45	1·53	−0·003	0·0011	*
Live-weight gain							
days 14 to 49	0·44	0·58	0·59	0·56	−0·001	0·0007	
days 50 to 91	0·73	0·66	0·69	0·68	0·003	0·0007	
days 14 to 91	0·60	0·62	0·64	0·63	−0·0003	0·0006	

Covariance regression coefficients

Intake	Days 14 to 49	Days 50 to 91	Days 14 to 91
b	0·019	0·053	0·037
s.e.	0·007	0·013	0·009
Live-weight gain			
b	0·006	0·019	0·013
s.e.	0·0059	0·0057	0·0047


7·0
6·0
5·0
4·0
3·0
2·0
Diet A
Diet B
Diet C
Diet D
40
120
200
280
360
440
520
600

pulp inclusion; however pre-weaning (days 14 to 49) maximum intake was achieved with the diet in which the proportion of barley to pulp was 67:33. In experiment 2, the intake of calves given the pulp-based diet was significantly greater between 36 and 84 days of age than that of calves given the cereal-based diet ($P < 0{\cdot}02$) but there was no difference between days 14 and 35.

There was no significant effect of diet on the live-weight gains of the calves in experiment 1 although there was a tendency for the inclusion of pulp (diets B, C and D) to raise the rate of gain up to weaning (Table 2). Overall (days 14 to 91) rates of gain were similar for all four diets. In experiment 2, rates of gain were significantly higher post weaning (days 35 to 84) and overall (days 14 to 84) in calves given diet C1 compared with those given A1.

Digestibility and nitrogen balance

The mean digestibility coefficients of DM, N, OM and fat in the milk replacer were 0·90, 0·90, 0·91 and 0·87 respectively. The digestibilities of milk replacer plus dry diet (period 1) and dry diet alone (period 2) used in experiment 1 are given in Table 4. If the digestibility of the components of the milk replacer and dry diet are assumed to be additive then in period 1 the DM digestibility of diets A, B, C and D were 0·74, 0·75, 0·71 and 0·68. The significant effect of period on diet digestibility (overall mean DM digestibility period 1 = 0·77 and period 2 = 0·70 ($P < 0{\cdot}001$)) and the higher digestibility of OM and N in period 1 compared with period 2 was probably due to the proportion of the diet supplied by milk replacer in period 1, although the effect is compounded by the increasing age of the calves. There was no effect of the age of the calf on the digestibility of ADF or lipid. Also, there was no significant diet × period interaction with regard to the digestibility of any of the dietary components or in the ratio N retention/N intake. There was a significant linear depression in the digestibility of DM and N as pulp replaced barley; digestibility of OM was best represented by a quadratic relationship with OM digestibility highest on diet B (67:33, barley:pulp) and lowest on the all-pulp diet. Digestibility of lipid was not effected by dietary treatment but that of ADF was increased as pulp replaced barley. Diet had no effect on the ratio of N retention/N intake. Urinary N as a proportion of N intake decreased as N digestibility decreased with increasing level of pulp inclusion.

The digestibility of diets A1 and C1 were similar to diets A and C. In the diet containing pulp (C1), digestibility of N tended to be lower and ADF higher than diet A1 (Table 5).

TABLE 3

Intake of dry matter (DM) and daily live-weight gain (kg/day) adjusted by covariance for differences in live weight at 14 days of age, of calves offered diets containing different proportions of barley and unmolassed sugar-beet pulp in experiment 2

	Diet			
	A1	C1	s.e.d.	Significance
No. of calves per treatment	31	34		
Intake (kg DM per day)				
Milk replacer				
days 14 to 35	0·32	0·32		
Pelleted diet				
days 14 to 35	0·73	0·70	0·055	
days 36 to 84	2·33	2·58	0·103	*
days 14 to 84	1·80	1·97	0·071	*
Live-weight gain				
days 14 to 35	0·45	0·40	0·054	
days 36 to 84	0·70	0·80	0·040	**
days 14 to 84	0·62	0·68	0·036	*

Covariance regression coefficients

Live-weight gain	Days 14 to 35	Days 36 to 84	Days 14 to 84
b	0·012	0·010	0·011
s.e.	0·0068	0·0047	0·0046

DISCUSSION

Intake of dry food by pre-ruminant calves has usually been related to the development of the rumen and to the maturation of the rumen mucosa. Numerous experiments have suggested that ruminal volatile fatty acids (VFA) are chemical stimulants of rumen mucosal growth and that inert bulk materials serve as physical stimulants for rumen muscular growth and increased rumen volume (Thivend, Toullec and Guilloteau, 1980). However, factors other than physical development of the organ may exert an influence on the voluntary intake of dry food by calves. The replacement of barley with pulp increased the intake of dry diet and daily live-weight gain of the calves although the overall DM digestibility of the diet was depressed, suggesting that the composition of the dry diet significantly affects voluntary food intake. Williams *et al.* (1985b) concluded that the pH of rumen contents was a major factor influencing voluntary food intake of calves and demonstrated that using unmolassed sugar-beet pulp rather than barley as the major energy source produced a higher (5·42 *v.* 4·94) and more stable rumen pH in the calf compared with the diet based on barley (Williams, Fallon and Innes, 1985a). In experiments 1 and 2, the maximum cumulative increase in weight compared with the barley-based diet were 3·08 and 4·2 kg respectively. No account has been taken of digesta-free changes in the weight of the digestive tract and it may be that part of the change in weight is associated with responses in gut tissue growth related to changes in intake.

The proportion of DM lost from samples of milled barley, unmolassed beet-pulp and citrus pulp incubated in nylon bags in the rumen of steers given a diet of hay were 0·63, 0·41 and 0·55 respectively after 26 h incubation and 0·81, 0·54 and 0·78 after 54 h incubation (P. E. V. Williams, unpublished results). Although the energy values for

TABLE 4

Digestibility of dietary components and nitrogen balance of calves given diets containing different proportions of barley and citrus/sugar-beet pulp

	Diet				s.e.d. for dietary effect	Significance
	A	B	C	D		
No. of calves per treatment	3	3	3	3		
Ratio of barley to pulp	100:0	67:33	33:67	0:100		
	Period 1 (38 days of age)					
Food intake (kg DM per day)						
Milk replacer powder	0·41	0·41	0·41	0·41		
Dry diet	1·08	0·83	0·95	1·07		
Digestibility coefficients						
Dry matter	0·78	0·80	0·77	0·74	0·015	*
Organic matter	0·79	0·81	0·78	0·77	0·015	*†
Nitrogen	0·81	0·81	0·77	0·73	0·014	***
Acid-detergent fibre	0·38	0·51	0·61	0·65	0·040	***
Lipid	0·73	0·77	0·68	0·59	0·080	
N retained/N consumed	0·44	0·44	0·49	0·41	0·038	
Urinary N/N consumed	0·36	0·37	0·28	0·32	0·022	*
	Period 2 (70 days of age)					
Food intake (kg DM per day)						
Dry diet	2·67	2·58	2·58	2·88		
Digestibility coefficients						
Dry matter	0·70	0·73	0·71	0·68	0·015	*
Organic matter	0·72	0·75	0·74	0·72	0·015	*
Nitrogen	0·73	0·77	0·69	0·64	0·014	***
Acid-detergent fibre	0·34	0·56	0·60	0·61	0·040	***
Lipid	0·69	0·67	0·70	0·70	0·080	
N retained/N consumed	0·36	0·41	0·39	0·36	0·038	
Urinary N/N consumed	0·37	0·36	0·30	0·28	0·022	*

† Quadratic component significant.

barley and unmolassed sugar-beet pulp are similar (13·7 and 12·7 MJ metabolizable energy per kg DM respectively; Ministry of Agriculture, Fisheries and Food, Department of Agriculture and Fisheries for Scotland and Department of Agriculture for Northern Ireland (MAFF), 1984), barley is degraded at a faster rate than pulp. Rumen-fluid pH is influenced by the rate of fermentation as it influences the production and absorption of VFAs, plus the buffering power of the rumen contents. In calves, the extent of VFA absorption is dependent on the production of VFAs which stimulate maturation of the rumen epithelium (Thivend *et al.*, 1980). However, in the early stages of dry food intake, if as a result of the rumen epithelium being undeveloped, absorption of VFAs is unable to increase to compensate for increased production, as occurs in adult ruminants (Thorlacius and Lodge, 1973), then high rates of production result in a depression in rumen pH, which may occur in calves given cereal-based rations. Furthermore, the rapid fermentation of cereals produces high proportions of lactate as the intermediate in the production of propionate (Hungate, 1966; Slyter, 1976; Elam, 1976) which also serves to depress rumen pH. Formulation of starter diets for calves using materials such as digestible pulp, which do not ferment as rapidly as cereals, may be beneficial in raising and stabilizing pH in the developing rumen.

Alternatively, dietary fibre buffers the gastrointestinal tract via the inherent buffering capacity of the specific fibre matrix (the cation exchange capacity), the quantity of cell wall ingested and the stimulatory effect of fibre on rumination and/or salivation (McBurney *et al.*, 1983). Sugar-beet pulp has a substantial cation exchange capacity

TABLE 5

Digestibility of dietary components in calves given diets based on either barley (diet A1) or barley and unmolassed sugar-beet pulp (diet C1)

	Diet			
	A1	C1	s.e.d.	Significance
No. of calves	6	6		
	Period 1 (45 ± 2 days of age)			
Food intake (kg DM per day)				
Dry diet	1·53	1·76		
Digestibility coefficients				
Dry matter	0·67	0·65	0·011	*
Organic matter	0·70	0·70	0·012	
Nitrogen	0·72	0·65	0·013	***
Acid-detergent fibre	0·44	0·53	0·035	**
Lipid	0·55	0·59	0·070	
N retained/N consumed	0·35	0·34	0·032	
Urinary N/N consumed	0·38	0·30	0·018	*
	Period 2 (78 ± 7 days of age)			
Food intake (kg DM per day)				
Dry diet	2·12	2·71		
Digestibility coefficients				
Dry matter	0·69	0·64	0·011	*
Organic matter	0·72	0·67	0·012	**
Nitrogen	0·76	0·65	0·013	***
Acid-detergent fibre	0·44	0·51	0·035	*
Lipid	0·65	0·56	0·070	
N retained/N consumed	0·37	0·35	0·032	
Urinary N/N consumed	0·38	0·30	0·018	*

(696 mmol/kg cell wall) and may play a major rôle in acid/base balance. The replacement of barley with pulp considerably increased the capacity of the diet to neutralize H^+ ions, raising the titratable acidity of the diet by a factor of 0·66 (Figure 1).

Motility of the abomasum and rumen is under the control of negative feedback mechanisms from receptors, sensitive to acid, present in the small intestine and rumen wall (Bell and Holbrooke, 1979; P. C. Gregory, personal communication). The presence of such acid-sensitive receptors in the calf would indeed implicate the acidity of rumen contents in controlling appetite for dry food.

In this discussion, emphasis has been placed on the relationship between food intake and rumen pH. However other factors such as palatability and the effect of the physical nature of the dietary components on saliva production, but which were not measured, may also influence food intake.

In both experiments 1 and 2, the DM digestibility of the diets was depressed as pulp replaced cereal; N digestibility decreased significantly but was partially compensated by an increase in fibre digestibility. The diets were formulated to contain similar crude protein concentrations and based on values given in MAFF (1984) the apparent digestibility of dietary crude protein was estimated to be about 0·82. In period 2, the mean N digestibility values of the four diets were 11 units lower than literature values. In diets A1 and C1, digestibility of N was 11 and 16 units lower in period 1, and 7 and 16 units lower in period 2, compared with the expected value. These differences indicate that compared with adult ruminants, which possess a functional rumen, the calf has a lower efficiency of N digestibility which is dependent on the substrates used in the diet. However, whether this decrease in N digestibility, especially in diets containing pulp, was specifically related to N derived from either pulp or soya cannot be determined.

The diets given contained 200 g ground straw per kg. Degradation of straw in the rumen i.e. bacterial cellulolysis, is severely depressed as rumen pH falls below 6·5 (Stewart, 1977; Mould and Ørskov, 1983/84). Incremental addition of pulp to the diet increased the proportion of ADF and also ADF digestibility. Williams *et al.* (1985a) reported that the pH in the rumen of the calf given similar diets to those used in the present experiment was only 5·4 when the calves were 80 days of age. The fact that bacterial cellulolysis was occurring in the calves is surprising and although it has been suggested that the inclusion of pulp moderated rumen pH, the value of 0·65 for ADF digestibility on diet D is indicative of considerable cellulolysis. Williams, Stewart, Macdearmid and Brewer (1986) could not account for efficient degradation of caustic-treated straw when rumen pH in steers was depressed by giving turnips. They suggested that cellulolytic bacteria colonizing materials in which cellulose is relatively available, may be less susceptible to changes in rumen pH and the same may be the case in calves given pulp.

The efficiency of utilization of dietary N did not differ between diets but urinary N excretion was lower, particularly during period 2, in calves consuming diets containing pulp. This strongly suggests that the lack of an increase in weight gain in response to increased food intake, as pulp replaced barley, was related to the reduction in N availability in diets containing pulp, since increases in weight gain were reported when the crude protein of starter diets was raised to levels between 170 and 180 g/kg (Guilhermet, 1977). Increased weight gain in response to increased food intake in calves given digestible pulp rather than cereal may be achieved if the digestible protein concentration of the pulp-based diet was raised to equal that of the cereal-based diet.

REFERENCES

ATKINSON, T., FOWLER, V. R., GARTON, G. A. and LOUGH, A. K. 1972. A rapid method for the accurate determination of lipid in animal tissue. *Analyst, London* **97:** 562-568.

BELL, F. R. and HOLBROOKE, S. E. 1979. The sites in the duodenum of receptor areas which affect abomasal emptying in the calf. *Research in Veterinary Science* **27:** 1-4.

Davidson, J., Mathieson, J. and Boyne, A. W. 1970. The use of automation in determining nitrogen by the Kjeldahl method, with final calculations by computer. *Analyst, London* **95:** 181-193.

Elam, C. J. 1976. Acidosis in feedlot cattle: practical observations. *Journal of Animal Science* **43:** 898-901.

Guilhermet, R. 1977. [Nutrition of the early weaned calf (calves for breeding).] In *Le Veau* (ed. P. Mornet and J. Espinasse), pp. 185-206. Maloine S. A. Editeur, Paris.

Hungate, R. E. 1966. *The Rumen and Its Microbes.* Academic Press, London.

McBurney, M. I., Van Soest, P. J. and Chase, L. E. 1983. Cation exchange capacity and buffering capacity of neutral-detergent fibres. *Journal of the Science of Food and Agriculture* **34:** 910-916.

Ministry of Agriculture, Fisheries and Food, Department of Agriculture and Fisheries for Scotland and Department of Agriculture for Northern Ireland. 1975. Energy allowances and feeding systems for ruminants. *Technical Bulletin 33.* Her Majesty's Stationery Office, London.

Ministry of Agriculture, Fisheries and Food, Department of Agriculture and Fisheries for Scotland and Department of Agriculture for Northern Ireland. 1984. Energy allowances and feeding systems for ruminants. *Reference Book 433.* Her Majesty's Stationery Office, London.

Mould, F. L. and Ørskov, E. R. 1983/84. Manipulation of rumen fluid pH and its influence on cellulolysis in sacco, dry matter degradation and the rumen microflora of sheep offered either hay or concentrate. *Animal Feed Science and Technology* **10:** 1-14.

Mould, F. L., Ørskov, E. R. and Mann, S. O. 1983/84. Associative effects of mixed feeds. 1. Effects of type and level of supplementation and the influence of the rumen fluid pH on cellulolysis in vivo and dry matter digestion of various roughages. *Animal Feed Science and Technology* **10:** 15-30.

Slyter, L. L. 1976. Influence of acidosis on rumen function. *Journal of Animal Science* **43:** 910-929.

Stewart, C. S. 1977. Factors affecting the cellulolytic activity of rumen contents. *Applied and Environmental Microbiology* **33:** 497-502.

Thivend, P., Toullec, R. and Guilloteau, P. 1980. Digestive adaptation in the preruminant. In *Digestive Physiology and Metabolism in Ruminants* (ed. Y. Ruckebusch and P. Thivend), pp. 561-585. MTP Press Limited, Lancaster.

Thomas, D. B. and Hinks, C. E. 1983. A note on the optimum level of roughage inclusion in the diet of the early-weaned calf. *Animal Production* **36:** 299-301.

Thorlacius, S. O. and Lodge. G. A. 1973. Absorption of steam-volatile fatty acids from the rumen of the cow as influenced by diet, buffers, and pH. *Canadian Journal of Animal Science* **53:** 279-288.

Van Soest, P. J. and Wine, R. H. 1968. Determination of lignin and cellulose in acid-detergent fibre with permanganate. *Journal of the Association of Official Analytical Chemists* **51:** 780-785.

Williams, P. E. V., Fallon, R. J. and Innes, G. M. 1985a. The effect of diet on the pH of contents in the developing rumen of the calf. *Animal Production* **40:** 571 (Abstr.).

Williams, P. E. V., Innes, G. M., Brewer, A. and Magadi, J. P. 1985b. The effects on growth, food intake and rumen volume of including untreated or ammonia-treated barley straw in a complete diet for weaning calves. *Animal Production* **41:** 63-74.

Williams, P. E. V., Stewart, C. S., Macdearmid, A. and Brewer, A. 1986. Diets with chemically treated straw for beef steers: effects of rapidly fermentable carbohydrate on food utilization, growth and bacterial cellulolysis. *Animal Production* **42:** 327-336.

(*Received* 26 *March* 1986—*Accepted* 30 *July* 1986)